INTEGRATION OF ECONOMIC PRODUCTION QUANTITY WITH DEFECTIVE ITEMS FOR MULTI-PRODUCT IN MULTI-PERIOD

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Mathematics)

Faculty of Science
Universiti Teknologi Malaysia

OCTOBER 2017

To my beloved family for their never ending support and care

ABSTRACT

Manufacturers often face material losses during the process of any specific production assemblies which are usually unpredictable. However, the attrition percentage can normally be obtained. In order to make sure that the demand is met despite attrition, the production needs to be planned wisely. Inefficient production planning can lead to the consumption of capital resources that can otherwise be put into better use elsewhere in the company. In this study, an inventory model that takes attrition into consideration with no shortage allowed is developed. An Economic Production Quantity with Attrition (EPQA) model is used to obtain the optimal production run size and the optimal production cycle. Then, an aggregate planning model for five periods of time is developed taking the optimal production run size obtained as the demand. This model will help the decision making process by determining the production quantity of products, use of overtime labor, number of workers to be hired or fired and the amount of inventory to be held in stock each period so that the demand is met and the annual total cost of operations is kept to the minimum. This new production policy can thus scientifically address the attrition problem, assist in decision making, help in resource planning and optimize the production process. For future study, the attrition could be included as an inherent parameter in material or inventory planning to make sure that required materials are sufficient to satisfy demands even when attritions exist.

ABSTRAK

Pengilang sering menghadapi kekisiran ketara semasa proses mana-mana pemasangan pengeluaran tertentu dimana kebiasannya adalah tidak dapat diramalkan. Walau bagaimanapun, peratusan keciciran selalunya boleh diperolehi. Dalam usaha untuk memastikan bahawa permintaan bahan dipenuhi walaupun keciciran berlaku, pengeluaran perlu dirancang dengan bijak. Perancangan pengeluaran yang tidak cekap boleh membawa kepada penggunaan sumber modal yang sepatutnya lagi baik digunakan oleh bahagian lain dalam syarikat. Dalam kajian ini, model inventori yang mengambil kira keciciran tanpa membenarkan sebarang kekurangan telah dibangunkan. Satu model Pengeluaran Kuantiti Ekonomi dengan keciciran (EPQA) digunakan untuk mendapatkan saiz pengeluaran optimum dan kitaran pengeluaran yang optimum. Kemudian, satu model perancangan agregat untuk lima tempoh masa dibangunkan mengambil saiz pengeluaran optimum yang diperolehi sebagai permintaan. Model ini membantu proses membuat keputusan dengan menentukan kuantiti pengeluaran produk, penggunaan tenaga buruh lebih masa, bilangan pekerja yang diambil dan dipecat dan jumlah inventori yang akan disimpan dalam stok untuk setiap tempoh masa supaya permintaan dipenuhi dan jumlah kos operasi tahunan ditetapkan pada tahap mininum. Dasar pengeluaran baharu ini boleh menangani masalah keciciran secara saintifik, membantu dalam membuat keputusan, membantu dalam perancangan sumber dan mengoptimumkan proses pengeluaran. Untuk kajian akan datang, keciciran boleh dipertimbangkan sebagai parameter yang ada dalam perancangan bahan atau inventori untuk memastikan bahan-bahan yang mencukupi untuk memenuhi permintaan walaupun keciciran wujud.

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LIST OF SYMBOLS

p_i	-	Daily replenishment or production rate at product *i*
r_i	-	Daily demand rate at product *i*
R_i	-	Annual demand in units
m	-	Number of annual orders or production runs
t_p	-	Transit time in years for replenishment order
P	-	Production cost
C	-	Setup cost
H_i	-	Holding cost per unit for product *i*
$TC(m)$	-	Total annual cost for m production runs per year
Q_i	-	Lot size for product *i*
N	-	Number of annual operating days
$_{ik}$	-	Production rate
x_{ik}	-	inventory level
$_{k}$	-	wo

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CHAPTER 1

INTRODUCTION

1.1 Overview

Production planning in manufacturing is the planning for smooth and optimum production in the company. It utilizes manufacturing resources, material availability and production capacity to serve customers. Production planning is a plan for future production. Quantity of manufacturing resources needed are determined and arranged. A production planning is made periodically for a specific time called horizon. To develop an efficient production planing, the production planner is required to work closely with sales department. A critical factor in production planning is the accurate estimation of the production capacity of available resources. A production planner also considers material availability, resources availability and future demand.

Economic Production Quantity (EPQ) is a strategy widely used in production planning practice because of its simplicity. Basic EPQ applies when demand of the product is constant over the year and there is fixed cost charged for each product produced, regardless of the number of units produced (Hsu, 2014). There is also a holding cost for each unit stored in storage. Recently research efforts have been made to extend the basic EPQ by relaxing the assumptions so that the model conforms more closely to real world problems. There are two major assumption the classical EPQ model. These are 1) the quality of output is of perfect quality and 2) the production rate is predetermined and fixed in advance.

Aggregate production planning (APP) model is a production planning activity. An APP for the production process is normally done in advance of 2 to 18 months to give an idea to the management as to what quantity of materials to be ordered, and when the product should be produced in order to minimize the total cost of the production over that period.

The concept of APP is to translate the forecasted demand and production capacity to future manufacturing plan for a family of products. APP greatly reduced the amount of data used during planning process and also the frequency of revising the plan (Baykasoglu, 2001). The common APP objectives are minimizing cost, minimizing inventory level, minimizing changes in work force level, minimizing use of overtime, minimizing use of subcontracting, minimizing changes in production rate, minimizing number of machine setups and maximizing profits. The research development in APP involves the consideration of multi-objective function, multi product, multi-period, multi demand and multi safety stock.

Both EPQ and APP models involve different implementation in manufacturing. Firstly, EPQ provides information on lot size that need to be run based on demand, production rate, setup cost and inventory cost. On the other hand, Secondly, APP determine amount of product, inventory and workforce level to meet demand requirements over a planning horizon. Demand is an important input in both APP and EPQ.

Attrition is throw out process of raw material during manufacturing process. The throw out of raw material for manufactured products are unpredictable. The amount of raw material which has been loss is not sufficient for next production batch thus the planner required to order those material or stock more to ensure there is no stopper for production. However, this situation leads to high inventory because the attrition quantity is unpredictable.

1.2 Motivation

Demand planning and inventory control are the most important operation activities in manufacturing and require management at its best. The demand data, inventory aging data, inventory analysis in each location are used to justify the order quantity and safety stock in production planning. Economic production quantity is important because holding too much inventory is costly and holding too low stock can incur stockouts, lost sales, and in some cases, production plan shutdown.

EPQ is designed to help inventory managers to maintain the right amount of inventory. EPQ model has been extended by considering the effect of imperfect production process (Porteus, 1986). Practically, imperfect quality items can be sometimes reworked and repaired. APP can be a valuable aid in planning production and workforce levels for a company because it provides a mean of absorbing demand fluctuations by smoothening workforce and production levels.

Inventory inaccuracy may occur due to shortage of materials, imperfect production processes, data input/output errors, transaction errors, cycle count errors and unreported scrap. In addition, attrition where material are discarded during production process, also affects inventory accuracy. This will cause immediate physical shortage to complete the product. Imperfect production process usually happens because of machine errors. This situation is often unavoidable when machines run at high speed. Thus, the planned quantity is not achieved and production tends to use more materials that should be consumed and this also tends to increase production setup cost. This situation causes the planner or purchaser difficulty to bring in materials on time due to extra materials needed earlier than expected to make up for lost production. In some circumstances, production planner tends to project for buffer stocks, but this result in higher inventory on production floor. An inventory model to determine optimal lot size which takes into consideration attritions rate helps the planner to decide on the number of workers and inventory level to execute the plan.

The influence of demand in APP is significant. Basically demand is a guideline for a planner in meeting customer requirement. Sudden material shortage for the demand due to attirition will have impact on the aggregate production planning done earlier and there is a continous need to revise the plan again based on current material availability. This will eventually impact customer service level.

1.3 Inventory Accuracy

Some manufacturing plants have no formal policy for reporting and reducing inventory used in subassemblies that must be reworked or scrapped. A detailed investigation is required to determine contribution of the scrap/attiririon rate to the inventory inaccuracies. The more complex of the subassembly to be reworked, the more difficult it is to capture the correct materials scrapped or used as replacement. Some subassemblies are so complex that it is difficult to determine what component is scrapped. When the component being reworked is very complex, routine stock adjustment needs to be done or the whole part needs to be scrapped off in the system with any salvagable components placed back on the system. The accuracy of reporting scrap/attrition is a particular area of concern for inventory control.

Operations people may be reluctant to assist in improving scrap reporting since such improvements ultimately may increase the scrap/attrition value in the system reporting. With this situation, there is frequent physical variance and production will have breakdowns on material supply to run production. Material planning is important and critical if attrition is expected in the near to actual planning period.

Another issue in inventory control is the lack of proper control on scraps. Poor or even no reporting of scrap can have major effects on the inventory accuracy. One way is to look at where the scrap is being placed and how it is being processed. The question is “What is the efficient way to do this?” The way it was done may be considered efficient on the plant. But it was discovered there were some other scrap lots which were not declared and were hidden for a certain period. Even the best system will not be able to give accurate inventory data when there is human interference.

Inventory accuracy is important for APP as it will calculate the material needed based on 6 months or above forecast to ensure production run without any material breakdown supply. A good system should include the attrition/scrap rate with demand loaded in system to sum up total material needed for the production

1.4 Attrition

Attrition refers to the situation when material flows out or is lost during production process. The loss of the materials usually happens when the machine has pick up errors, or when the machines are down. Planner will do planning based on system data on material quantity. If the system shows the quantity is available the model will proceed to production, and production will perform material kitting at sub stores to allocate materials from main store, to run certain planned products. Once production is completed, those materials will be returned to substores and re-count process on the material will be performed. The quantity during re-count may not be the same with the required quantity in the system. This situation creates “attrition”.

In this study, attrition happens mostly for small/tiny parts such as resistors and capasistors which caused physical shortage on next production and product produced as defective. Planners face difficulty to plan if there is unreported attrition, or attrition reported is not done for certain period of time so that the data is out of date. Manufacturing company practice to scrap materials weekly to ensure the inventory data is accurate and alert the planner to purchase those material in short supply immediately.

1.5 Background of Research

EPQ model determines the quantity a company should produce in order to minimize the total production cost. EPQ was developed by Taft in 1918, as an extension of Economic Order Quantity (EOQ) (Taft, 1918). Its fundamental is that the quantity of product should be manufactured in single or multiple batch to ensure total cost are minimized. The cost includes setup costs for machine and inventory holding cost. Thus, total cost of EPQ value should comprise of each cost at its minimum value. This is achieved by differentiating and finding minimum for the equation of the total cost.

A few studies have been done to address the EPQ model with rework. One way is to incorporate the effect of defective items in classical EPQ model (Porteous, 1986). These defective items can be reworked in the same cycle. The author found that optimal EPQ with rework is smaller than classical EPQ and the smaller the lot sizes, the smaller the defective rate. An optimal result is achieved for finite production model under effect of reworking imperfect quality items, defective items are reworked and repaired (Hayak and Salameh, 2001). A finite production model had been developed with consideration of random defective rate, scrapping and reworking of repairable defective items and backlogging by Chiu (2003). Another study allowed the simultaneous determination of production to include rework lot and batch sizes (Buscher and Lindner 2007). In general, defective item is the product which requires rework or scrap off if unable to rework whereby attrition is the process which produced the defective item. Thus, this research will consider attrition rate in the inventory model to ensure produced product able to meet customer demand.

APP was first conceived in an important series that appeared in the mid 1950s. Holt *et al.* (1955) first discussed the structure of the problem and introduced quadratic cost approach. Later, a study of Holt *et al.* (1956) concentrated on the computational aspect of a model where a software was used to obtain results. The computational aspect is production planning accompined with aspect of model which calculates the amount to be produced, required number of worker, material to be place order. In simple word, all the information required to run a production. They found that the managers were going from one crisis to another with uncertain forecasts of frequent demand fluctuates for multiple products and huge fluctuations between overtime and idle time

Initially, APP was solved by quadratic programming. Later it was remodeled so that linear programming (LP) technique can be applied to solve the problem. A standard LP model was developed for the APP. In the begining fluctuations within demand is expected to be slower so the imprecise natures did not significantly affect the LP results. Later on, real situation forced consideration for demand fluctuations. Stochastic programming (SP) was used to solve the production problems. However, SP generally does not model the real situation accurately as the approach does not provide any control point to variability on solutions with different scenarios (Sadjadi 2011).

Regression analysis based on managers' past performance to develop decision rules for aggregate planning was introduced by Bowman (1956). Bowman's work had far impact on operations management, particularly in artificial intelligence. He developed two heuristic rules, one for size of workforce and another for production rate, and tested both his model. Jones (1967) converted the HMMS (Holt, Modigliani, Muth and Simon's work) model into a 20-dimension response surface and used a search decision rule to find the solution (Taubert 1968). These are mathematics approach done in previous study of APP. (Baykasoglu, 2001) listed various studies on APP in the early years

- Trial and error method (Noori, 1995)
- Search decision rule (Taubert, 1968)
- Management's coefficients method (Bowman, 1956)
- Production switching heuristic (Wang, 1995)
- Transportation method (Bowman, 1956)
- Goal programming (Tabucanon, 1985)

- Simulation models (Bakir, 1996)

The objective of an APP maybe single, dual or multiple in nature. In a single objective model, the minimization of the total cost function is usually the objective. This generally consists of production cost, inventory cost, shortage cost and cost of changes in labor level. In bi-objective models, the minimization of total cost is still the main objective, and the other objective is either maximization of service level, minimization of changes in work force level, or minimization of variability of total cost. A multi-objective plan is a combination of the single objective with two or more of the others

Under general conditions, companies will likely face fluctuating demands. APP need to find ways to minimize the related costs in view of variation in demand and sales by adjusting production rates, workforce levels and inventory levels (Canel, 2013). The adjustment is carried out using a variety of operation research methods. There is a host of methods used to solve problem but APP still remain a problem. The demand fluctuation not only affect the planning but also effect on the inventory level. A high inventory level leads to high aging on the inventory if there is no extra demand to absorb the product. In addition, planning for real-situations needs to include effects of attirition. Physical shortage can occur unexpectedly and planners face difficulty on expediting on the next arrival of the material. Identifying the problem in early stage will prevent the issue from happening in future. The process of identifying is shown step-by-step in Figure 1.1

MOTIVATION

Imperfect production process happens due to equipment error and cannot be avoided during production process. Attrition is one of the imprefect production process which cause the produced quantity is not produced as per planned by the planner. The situation cause consumption of raw material consumed earlier than expected and planner tends to order more raw material in advance which results in financial loss of the company. In some circumstances, the planner tends to have buffer stock which results in higher inventory holding cost on production floor. Therefore modeling an EPQA model and integrating it with APP model to enable planner to decide on lot size to run and resources required are necessary

EXISTING WORK IN BOTH APP AND EPQ	
EPQ	APP
The effect of imperfect process in EP leads to production of defective products Recent modification done on EPQ mo lead to optimal production quantity solution in shortage is allowed. But the solution does not solve the problem ir overall.	The advantage of APP model is advance production planning and gives an idea to management for resources planning in situation on production demand which changes due unexpected material shortag during production process. Thus, frequent revise in production planning is required.

LIMITATION

Existing inventory management system do not consider attrition rate. Modification of EPQ model with inclusive of attrition rate. Two important models involve in production planning that are APP and EPQ were not linked together.

DESIRED SOLUTION

The role of demand of product is triggering all the other cost in the industry. The material availability will ensure the production runs smoothly. This research further proposes a mathematical modelling to find optimal production quantity inclusive of attrition and based on the solution find the resources required to execute the production with shortage not allowed

Figure 1.1 Flowchart of Problem Formulation

1.6 Problem Statement

For a production to run smoothly, a manufacturing company needs to have a proper production planning. However, it is difficult to plan for production when the demand is deterministic Attrition that happens during production adds to the fluctuation of the demand and produced defective products. If the attrition rate is not considered in the production planning, this may cause immediate physical shortage of the raw material and production may be interrupted and results in financial loss to the company. In order to overcome this problem, this research considers an Economic Production Quantity with Attrition (EPQA) model under deterministic demand assumption and, taking into account the attrition rate during the production with shortage not allowed, in finding the optimal production level. From the solution, the APP model will then use to determine the resources required to meet the production level. In this work, the EPQA and APP models will be integrated

1.7 Research Question

The problem statement raises several research challenges. These challenges will be addressed by providing answers to the following questions:

1. What are the roles of demand in production planning and what is the impact if physical shortages happen?

    i. What will be the impact to production when attrition happens in unexpected manner?

    ii. How to prevent a production run from interruption?

    iii. What is the solution to optimize finished goods rather than having extra buffer stock in production floor?

2. How can APP runs effectively under imperfect situation?

   i. What is the production quantity for each product given that the production cost, inventory cost, worker's cost, hiring and firing cost and the cost varies within the planning period?

   ii. How to ensure the production runs in minimum total production cost?

   iii What is the purpose of the both model integrated?

3. What is the impact when product cost, worker's cost, inventory varies?

   i. What is the allowable increase of costs to minimize total production cost?

   ii. How to ensure the varies of production costs does not impact number of quantity to be produced?

1.8 Research Objective

The principal objective of this study is to develop a realistic integration of APP and EPQA for multi-product in multiperiod to reduce the gap between existing literature and practical implementation. The specific objectives of the study have been identified as follows:

1. To analyze the demand behavior in situation of physical shortage that occurs due to attrition rate.
2. To determine the optimal lot size with attrition and no shortage is allowed using EPQA model
3. To determine the optimal production and resource level using APP model under EPQA demand assumption.
4. To investigate the effect of changes on the cost of parameters

1.9 Scope of the Research

The scope of the study is focused on the integration of EPQA and APP. This study will assume situation of no shortage allowed, deterministic demand and imperfect process. The planning horizon will be 5 months. The investigation will be mainly on how to ensure no shortage even though in situation of imperfect production process without revising the production planning due to material shortage.

1.10 Significance of the Research

EPQA is a model developed with one of them imperfect process known as attrition. The model is mainly to obtain optimal lot size of production with known attrition quantity followed by APP model to find manufacturing resources. The integration of EPQA and APP benefits the production planner in term of advance planning based on the lot size inclusive of attrition and the required manufacturing resources.

1.11 Organization of Thesis

Chapter 1 introduces the research discipline, which is EPQ and APP for multi-product in multi-period. It also includes discussions of the problem background, problem statement, research objectives, significance as well as scope of the research.

Chapter 2 provides an extensive literature review of the study area. Extensive background work on the research discipline is also discussed here in addition to the chosen EPQ model i.e. behavior of demand and APP model.

Chapter 3 discusses the procedure in conducting the research which include assumptions made, research design and procedure and operational framework.

Chapter 4 presents the development of the EPQ model with attrition and no shortage allowed. The model gives the economic production quantity and the total production cost.

Chapter 5 presents the development of APP Model under EPQ demand. The model is solved using LINGO 15.0. The solution presents number of workers required, the optimal production quantity and resources level in fulfilling the demand requirement for each period. The sensitivity analysis is carried out to find the effect of various production cost on the number of required worker's. The reason is to find the minimum allowable changes of cost on which reflects to change on number of worker's.

In the final chapter, a summary of the entire research is done before concluding with the research findings. In addition, a few recommendations are also forwarded for future researches.

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